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GUIDELINES TO IMPROVED PERFORMANCE AND FUEL CONSUMPTION OF PROPANE CONVERSIONS

J. S. Wallace
L. Segal
Engine Research and Development Laboratory
Department of Mechanical Engineering
University of Toronto

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TABLE OF CONTENTS

PAGE

1/ INTRODUCTION 1

2/ PROPANE CHARACTERTISTICS 2

3/ REQUIREMENTS FOR SATISFACTORY ENGINE OPERATION ON PROPANE 5

3.1/ Maximum Power Output 5

3.2/ Fuel Consumption 6

3.3/ Exhaust Gas Temperatures 11

3.4/ Effectiveness of Carburetion Systems 14

4/ RECOMMENDED TUNING PROCEDURES 18

4.1/ Air/Fuel Ratio 18

4.2/ Ignition Timing 21

4.3/ Vacuum Advance 24

1/ INTRODUCTION

This report provides engine tuning guidelines for technicians converting gasoline-fuelled vehicles to operate on propane. Use of the procedures recommended should result in improved fuel consumption and better performance.

These guidelines are based on a series of engine dynamometer tests carried out at the Engine Research and Development Laboratory of the University of Toronto Mechanical Engineering Department (UTME) for the Ontario Ministry of Transportation. Available propane carburetion systems were tested on engines representative of passenger cars (3.8 L V-6), light trucks/vans (4.9 L I-6), and medium-duty trucks (6.1 L V-8). In addition to evaluating the carburetion system itself, experiments were carried out to improve the fuel consumption by optimizing the ignition timing and air/fuel ratio for a wide range of operating conditions. Significant improvements over the as-installed fuel consumption were achieved for all three engines.

Propane carburetion systems are currently at a rather low level of engineering development compared to gasoline carburetors. Gasoline carburetors are carefully tailored by the manufacturer to provide the best combination of maximum power, low fuel consumption and low emissions for each particular engine. On the other hand, installers of propane carburetion systems must take a few universal carburetor models and try on their own to achieve the same results as the original engine manufacturer. With this difficult task to perform, and little information available for assistance, it is not surprising that most propane conversions are not tuned to provide the lowest fuel consumption and best maximum power.

This report provides installers with additional information on tuning the propane-fuelled engine to achieve better fuel consumption and performance.

2/ PROPANE CHARACTERISTICS

In order to better understand the engine requirements for best operation, it is necessary to know something about the fuel itself. Propane fuel for vehicles is actually a mixture of propane, butane, propylene and other hydrocarbons which are gases at atmospheric pressure and temperature but which liquefy at higher pressures. Fuel for spark ignition engines must meet certain minimum requirements and is known as Grade I propane in Canada and HD-5 propane in the United States. The main requirements are that the mixture contain a minimum of 90% by volume of propane and that the propylene content be no greater than 5%. The amount of propylene is limited because it lowers the octane rating of the fuel mixture.

The tank pressure necessary to keep the fuel liquefied changes as the temperature changes, as shown in Figure 1. A minimum pressure of about 2 atmosphere (14.7 psig, 0.203 MPa) is required to operate the propane carburetion equipment. From Figure 1, it can be seen that at temperatures below -25°C, the tank pressure is not high enough for proper operation. At the other end of the temperature scale, the figure shows that the tank pressure can be quite high on a hot summer day. For this reason, propane tanks are pressure vessels, very strong tanks designed to resist this pressure, rather than the simple sheet metal containers used to store gasoline. A pressure regulator is necessary to reduce the tank pressure to near atmospheric pressure in the carburetor. The function of the pressure regulator is to maintain a constant fuel pressure at the carburetor inlet regardless of the tank pressure (which may vary by a factor of up to eight times, depending on the temperature) or the amount of fuel demanded by the engine. To provide good control of the pressure, commercial regulators decrease the pressure in two or even three stages.

As the pressure drops in the regulator, the propane changes from a liquid to a gas. Propane, like every other substance, requires an addition of energy as it is changed from a liquid to a gas. An example of this is the boiling of water. Even after water is heated to 100°C, much more heat must be added to the water before it all changes to steam. In the propane regulator, the heat required to vaporize the fuel is provided by engine coolant flowing through passages cast into the regulator body. The amount of heat required is directly proportional to the amount of propane required by the engine.

With the engine at normal operating temperature, the coolant is able to vaporize the propane even at full load and highest operating speed. However, with a cold engine, the coolant temperature may be inadequate to vaporize propane if large amounts of propane are demanded (high speed, high load). Under these conditions, freezing may occur in the regulator, which results in blockage of fuel flow to the engine. This problem is characteristic of all propane

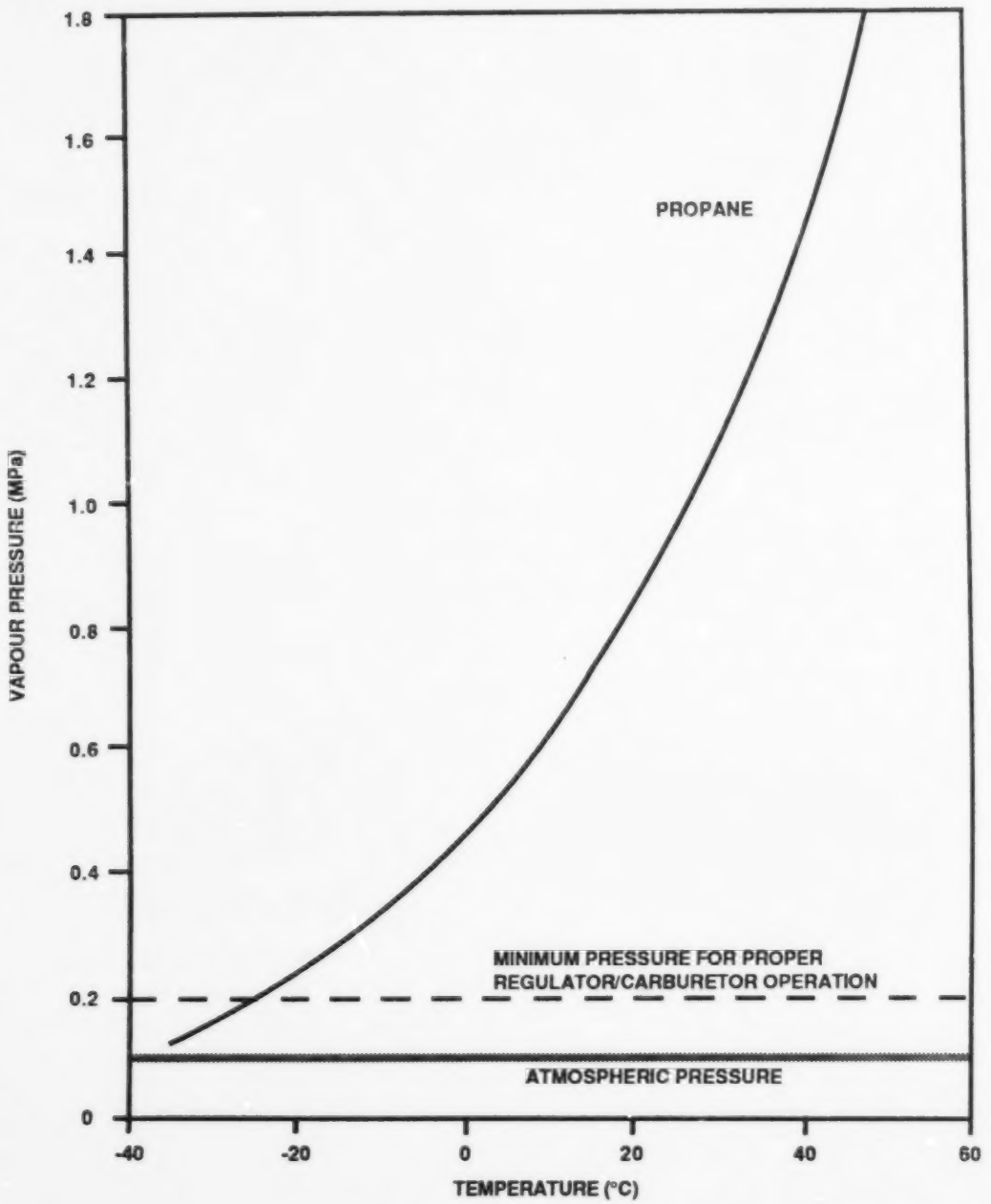

Figure 1/ Propane Tank Pressure for Various Ambient Temperatures

carburetion systems and can only be solved by using some supplementary heating source, such as an electrical heating element, during the engine warm-up period. Unfortunately, none of the commercially available propane carburetion systems have a provision for supplementary heating.

Another characteristic of propane is that a litre of propane contains 28% less energy than a litre of gasoline. Assuming that an engine operates on propane and gasoline with equal efficiency, more litres of propane will be consumed to carry out a given task. Fortunately, engines generally operate on propane with greater efficiency than on gasoline so that the increase in volume of fuel consumed is not as great as the energy comparison suggests.

For complete combustion, the proper air/fuel ratio for HD-5 propane is 24 by volume and 15.8 by mass. In other words, 24 litres of air are required for every litre of propane vapour consumed by the engine or 15.8 kg of air for every kg of propane. For gasoline, the correct air/fuel ratio is 59.5 by volume and 14.7 by mass.

During the intake stroke, a fixed volume of gas enters the cylinder of an engine. The power output of the engine depends on the energy content of that volume of gas. The energy content of a propane-air mixture with the proper air/fuel ratio for complete combustion is 2.3% less than that of a gasoline vapour-air mixture with the proper air/fuel ratio for complete combustion. If all of the gasoline entering the cylinder is still in the liquid form, then the energy content of the propane-air mixture is 3.1% less. Thus, a propane-fuelled engine can be expected to show a loss in power between 2.3 and 3.1% compared to a gasoline-fuelled engine. Other factors affect the maximum power output, however, as will be discussed in the next section.

3/ REQUIREMENTS FOR SATISFACTORY ENGINE OPERATION ON PROPANE

This section examines the factors that affect the maximum power output, fuel consumption and emissions of propane-fuelled spark ignition engines.

3.1/ Maximum Power Output

For a particular engine, the maximum power output depends on:

- the amount of fuel-air mixture taken into the engine;
- its volumetric energy content;
- the air/fuel ratio;
- the ignition timing.

In the previous section, it was noted that the energy content of a given volume of propane-air mixture is 2.3 to 3.1% less than that of the same volume of gasoline-air mixture. Thus, a propane-fuelled engine can be expected to show a loss in power between 2.3 and 3.1% compared to a gasoline-fuelled engine if the same volume is inducted into the engine.

The amount of air and fuel inducted into an engine is restricted by flow resistance in the carburetor, intake manifold, intake ports, and intake valves. Changing the carburetor of an engine affects its volumetric efficiency, a measure of how completely the engine cylinders are filled with air and fuel at each intake stroke. Every carburetor or gas mixer has some resistance to the flow of air and fuel through it. The resistance gets larger as the flow increases.

To minimize the power loss, it is important to install a propane carburetor that has no greater flow resistance than the original gasoline carburetor. Gas mixers of the type that fit into the air intake of the standard carburetor will have a power loss greater than the 2.3 to 3.1% already mentioned, because the flow restriction of the gas mixer is in addition to that of the standard carburetor. Thus, less air and fuel will reach the engine's cylinders so less power will be produced. Wherever possible, a complete propane carburetor should be used rather than a gas mixer if maximum power output is a consideration. Clearly, a gas mixer must be used if dual-fuelling capability is necessary, but it must be recognized from the outset that while operating on propane some power will be lost. Given the widespread availability of propane throughout Canada, there is really no reason to retain the gasoline-fuelling capability.

The amount of air and fuel delivered to the engine cylinders depends on the temperature, increasing as the air temperature decreases. (Fuel temperature is not so important since it is a small fraction of the mixture supplied to the engine.) Practically speaking, the air temperature can be decreased in a propane-fuelled engine by blocking off the intake manifold heating system and changing the standard coolant thermostat (88°C, 190°F) to a lower temperature (71°C,160°F). This change increases the volumetric efficiency by several percentage points.

With a properly sized propane carburetor (one with low flow resistance) and these changes to reduce the intake system temperature, the propane-fuelled engine may actually produce more power than the gasoline-fuelled version simply because it takes in more air and fuel.

The temperature of the air supplied to the carburetor is also important. In buses and cab-over trucks with high underhood temperatures, an air duct should be installed to provide cool outside air to the carburetor. This will increase the power output of the engine and will also help to prevent knock.

The air/fuel ratio has a major effect on the maximum power output. Figure 2 shows how the wide open throttle (WOT) brake power output of a 4.9 L six-cylinder engine depends on the air/fuel ratio. The chemically correct air/fuel ratio is 15.8 for HD-5 propane and 14.7 for gasoline. Air/fuel ratios higher than this are lean (shortage of fuel) while ratios lower than this are rich (excess fuel). The maximum power with propane is produced with an air/fuel ratio of about 14.5. Note that at the four speeds tested, the maximum power output with propane is roughly equal to that of the original gasoline engine. Operating with too lean a mixture reduces the power considerably. Improper setting of the air/fuel ratio is a major cause of reduced power outputs with propane-fuelled engines.

Finally, ignition timing also affects the maximum power output, although not as much as air/fuel ratio. Figure 3 shows how the brake power output of the 6.1 L V-8 engine depends on ignition timing, measured in degrees before top dead centre (BTDC), at 1200 rpm for three different air/fuel ratios. The optimum timing is indicated by the hourglass symbol. More spark advance is required for lean mixtures. As is the case with gasoline, more spark advance is required at high speeds. Recommendations for centrifugal advance are given in the next section.

3.2/ Fuel Consumption

Air/fuel ratio has a strong effect on fuel consumption.

Figure 4 shows the WOT fuel consumption for the Ford 4.9 L I-6 engine for various air/fuel ratios. Leaning the mixture (increasing the air/fuel ratio) decreases the fuel consumption. However, since the power output also decreases as the air/fuel ratio is increased, this figure doesn't indicate which air/fuel ratio is most efficient.

If the fuel consumption is divided by the work output, creating a ratio called the brake specific fuel consumption (bsfc), and the same data is replotted (Figure 5), a definite minimum is indicated. The brake specific fuel consumption is the fuel consumption per unit work output (g/kWh or lb/hph) and is the inverse of efficiency. In other words, when bsfc is a minimum, the efficiency is maximum. Figure 5 shows the effect of air/fuel

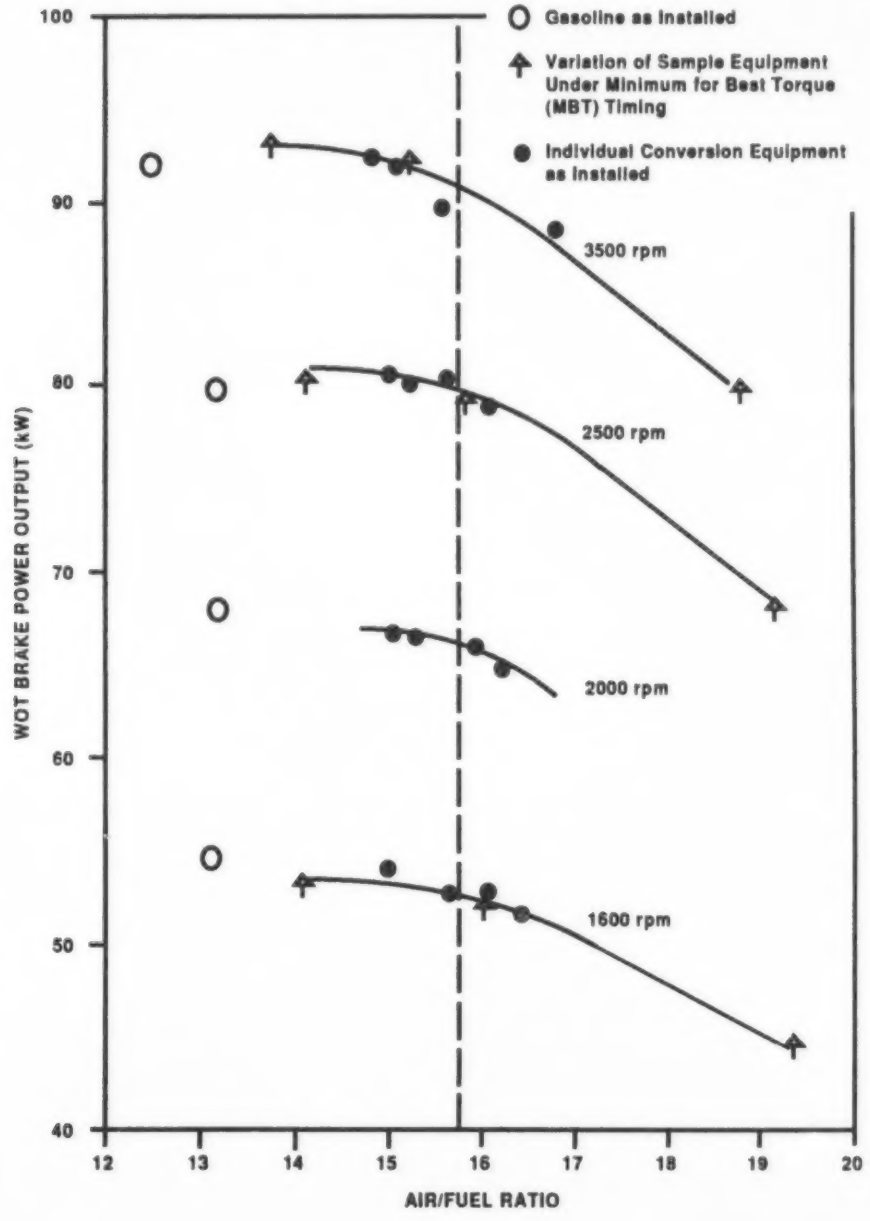

Figure 2/ The Effect of Air/Fuel Ratio on Power Output, Ford I-6

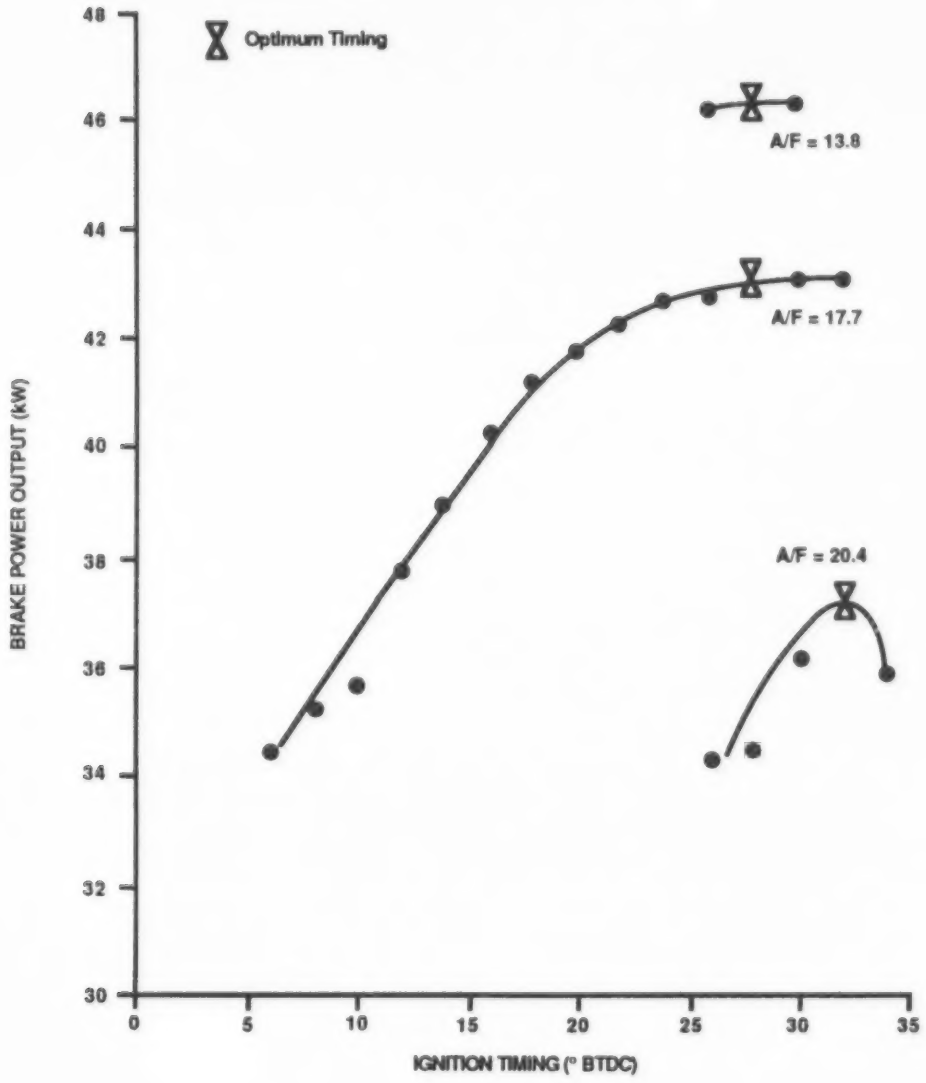

Figure 3/ Variation of Brake Power Output with Ignition Timing at Different Air/Fuel Ratios, Ford V-8 at 1200 rpm with full load

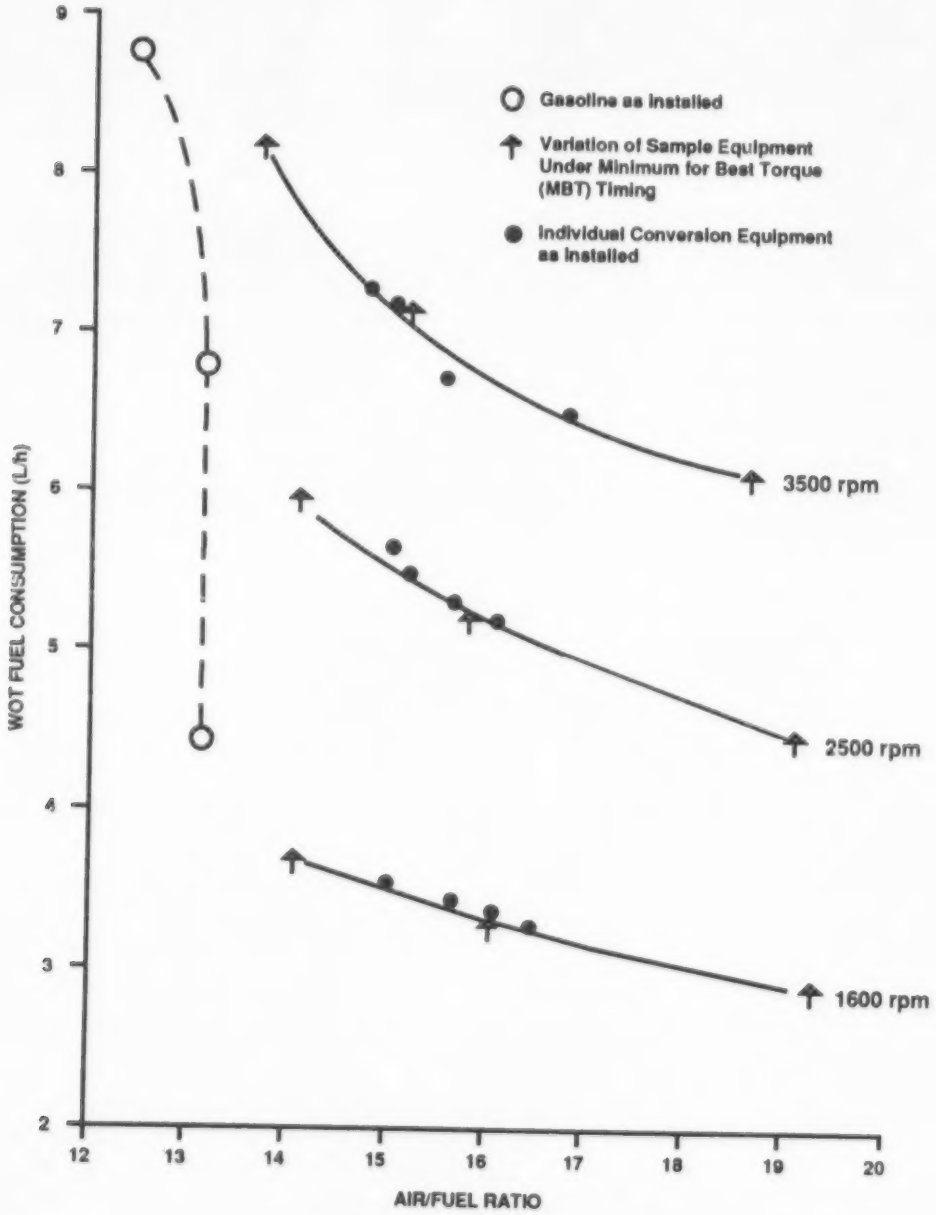

Figure 4/ Variation of Fuel Consumption with Air/Fuel Ratio at Different Speeds, Ford I-6

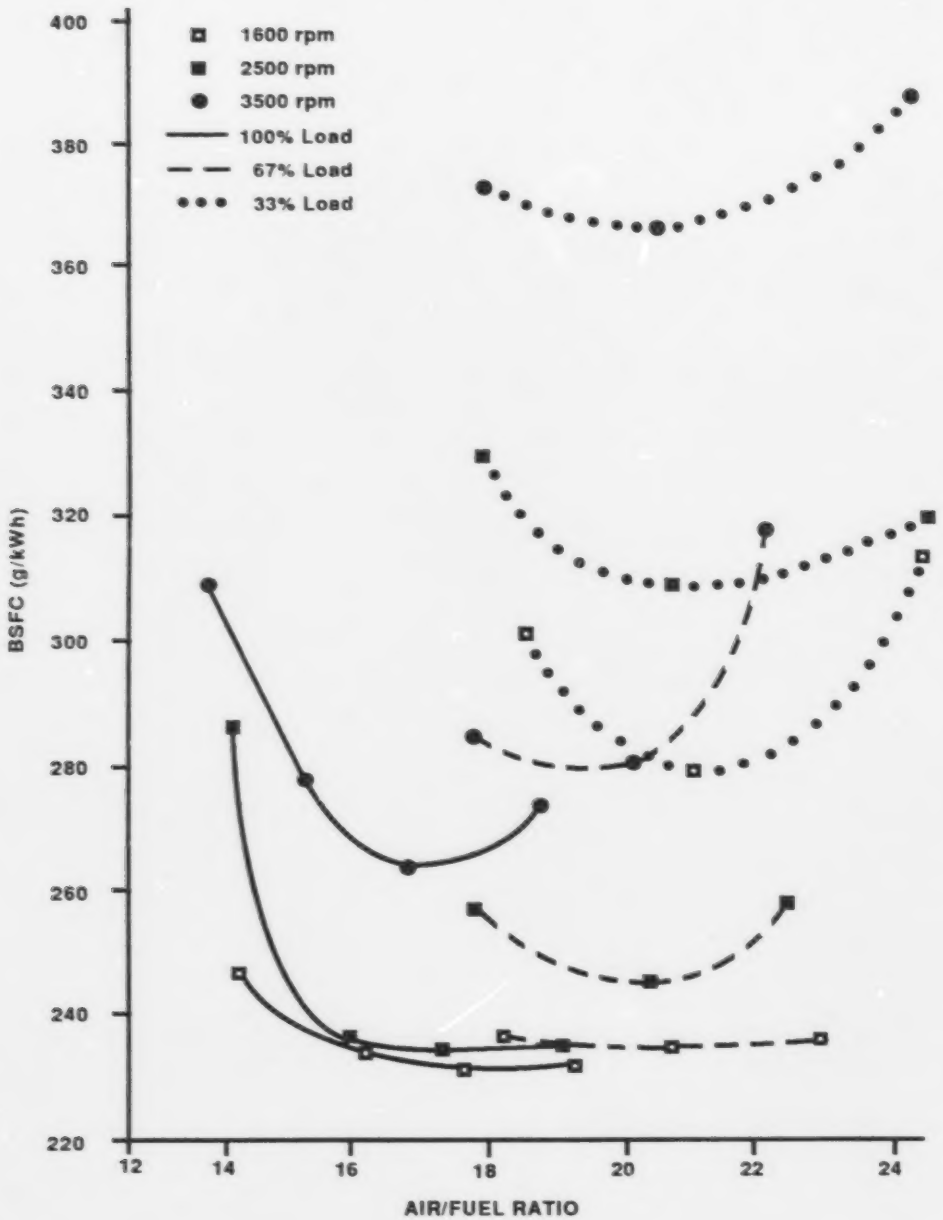

Figure 5/ Brake Specific Fuel Consumption at Various Air/Fuel Ratios, Ford I-6

ratio on bsfc for three loads and three speeds. All points included had the timing adjusted to the value which resulted in lowest fuel consumption for that air/fuel ratio. The minimum fuel consumption is obtained with a lean mixture, an air/fuel ratio of about 20-21 at part load and about 17-18 at full load. Note that a very small change in air/fuel ratio produces a large change in fuel consumption.

Ignition timing also influences bsfc, as illustrated by Figure 6. These results are again for the Ford I-6 engine with an IMPCO carburetor, but results from the other two engines illustrate the same trends. Results are shown for the air/fuel ratio provided by the carburetor as installed and for a leaner air/fuel ratio. The leaner mixture is slower burning and therefore requires more ignition advance. Note that improper setting of the timing can result in a large change in fuel consumption.

3.3/ Exhaust Gas Temperatures

Exhaust gas temperature is a relative indication of exhaust valve temperature. Concern about exhaust valve life results from the belief that combustion temperatures are higher with propane. As noted in Section 2, if both propane and gasoline are vapours, their peak combustion temperatures are nearly equal. However, under normal circumstances, some gasoline enters the combustion chamber as liquid droplets. The vaporization of these liquid droplets cools the cylinder, resulting in lower peak combustion temperatures. Experimental results from the tests, however, show little difference in the measured exhaust gas temperatures for propane and gasoline if the air/fuel ratio is properly adjusted. Peak combustion temperatures, and therefore exhaust gas temperatures, are strongly influenced by the air/fuel ratio. This is shown in Figure 7, where measured exhaust gas temperatures from the Ford I-6 for both propane and gasoline operation are presented for three different speeds. At the lower speeds, the exhaust gas temperatures for propane are actually less than those for gasoline.

The figure shows that the maximum exhaust gas temperature occurs with a chemically correct mixture. Operation at full load with a rich mixture (air/fuel ratio of about 14.5) for maximum power or a lean mixture (air/fuel ratio of about 17-18) for minimum fuel consumption will result in exhaust gas temperatures which are comparable to those for the gasoline-fuelled engine.

If exhaust gas temperatures comparable to those of the gasoline-fuelled engine can be obtained by using optimum air/fuel ratios, this suggests that temperature is not the factor contributing to the excessive valve seat wear experienced in some propane conversions. Extensive testing carried out by engine manufacturers and oil companies at the time of the change to unleaded gasoline suggests that at spot contact, welding actually occurs between the valve and valve

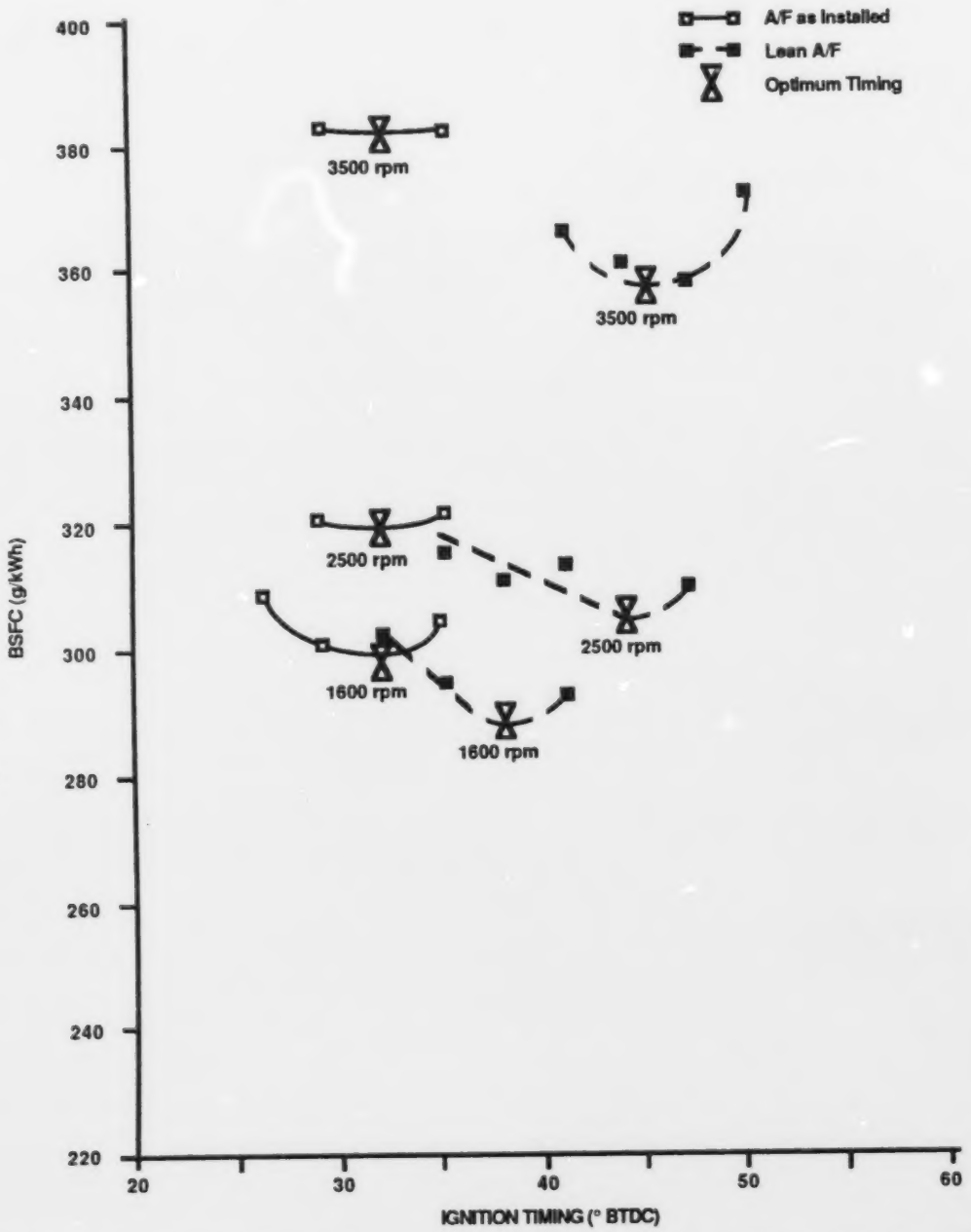

Figure 6/ Dependence of Brake Specific Fuel Consumption on Ignition Timing, Ford I-6 1/3 Load

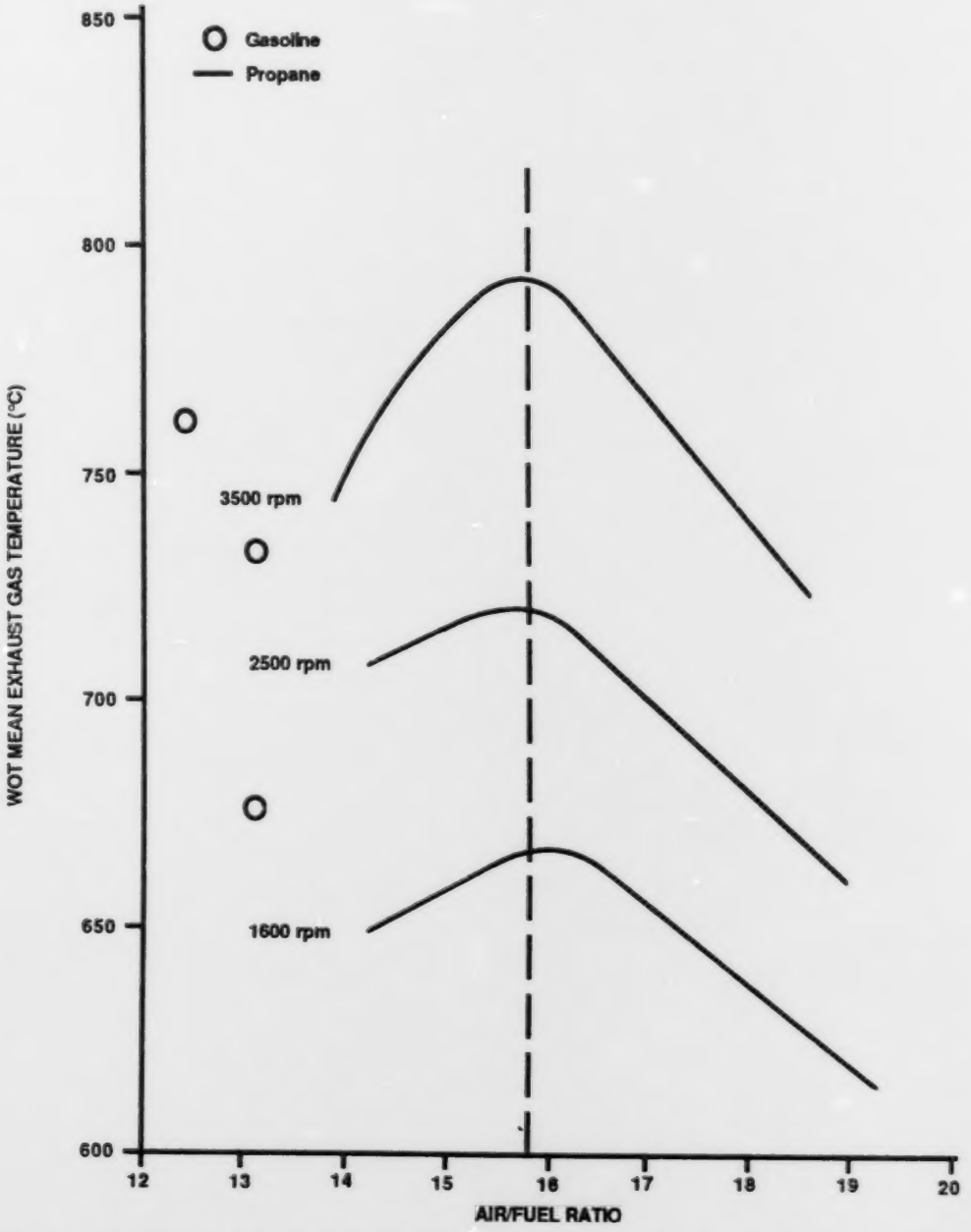

Figure 7/ Dependence of Exhaust Gas Temperatures on Air/Fuel Ratios, Ford I-6

seat. Subsequent valve opening results in small bits of metal being removed from the seat. The combustion of leaded gasoline produces a solid lubricant, lead oxide, which prevents this type of wear.

Present unleaded fuels still contain some lead, so the problem of valve seat wear isn't as severe as with gaseous fuels (natural gas and propane). New regulations requiring complete removal of lead from gasoline may force engine manufacturers to make material changes in valves and seats which would also provide excellent service with propane and natural gas. For the moment, induction hardened valve seats in passenger car and van engines should provide reasonable service with propane for most users, but problems may be experienced if the engine is operated at high speeds for long periods of time or if the vehicle is used to tow a trailer.

3.4/ Effectiveness of Carburetion Systems

The previous sections have shown that air/fuel ratio has a strong influence on maximum power output, fuel consumption and exhaust gas temperatures. Thus, the ability of a propane carburetion system to maintain the desired air/fuel ratio will in large measure determine the success of a propane conversion. The full-load optimum air/fuel ratio, about 14.5, produces maximum power while the part-load optimum air/fuel ratio, about 20 - 21, results in minimum fuel full power and about 16 - 17 for minimum fuel consumption.

Figures 8 through 11 show how well the various systems tested control the air/fuel

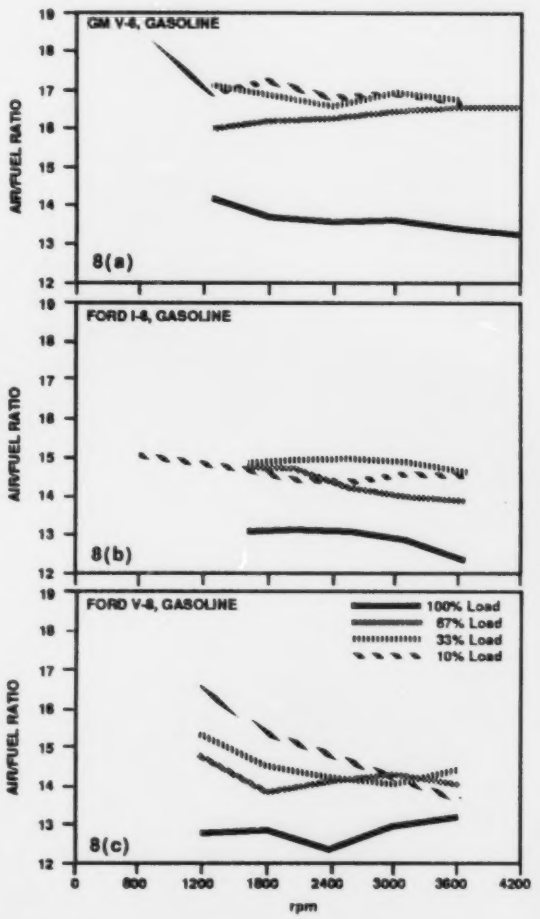

Figure 8/ Air/Fuel Ratio Variation with Speed and Load for Gasoline Engine

ratio throughout the engine speed and load range. Starting with the gasoline carburetors in Figure 8, note that the gasoline carburetor for the GM V-6 (Figure 8a) is a well-developed unit – keeping the air/fuel ratio near optimum under all conditions. Such careful control is required so that this passenger car engine can meet the emissions standards applicable to passenger cars. Truck engines are not subject to the same requirements, so the carburetor can be a simpler and cheaper device. However, as the plots for the Ford I-6 (8b) and Ford V-8 (8c) carburetors indicate, the light-load mixtures are too rich, resulting in a significant penalty in fuel consumption. Both carburetors provide a near optimum mixture for full power.

Figure 9 shows the results for the IMPCO carburetors. The regulator-vaporizer used with all three engines was fitted with a vacuum operated emission control device, EC1, to enrich the mixture at full loads. (Its principle of operation is similar to that of

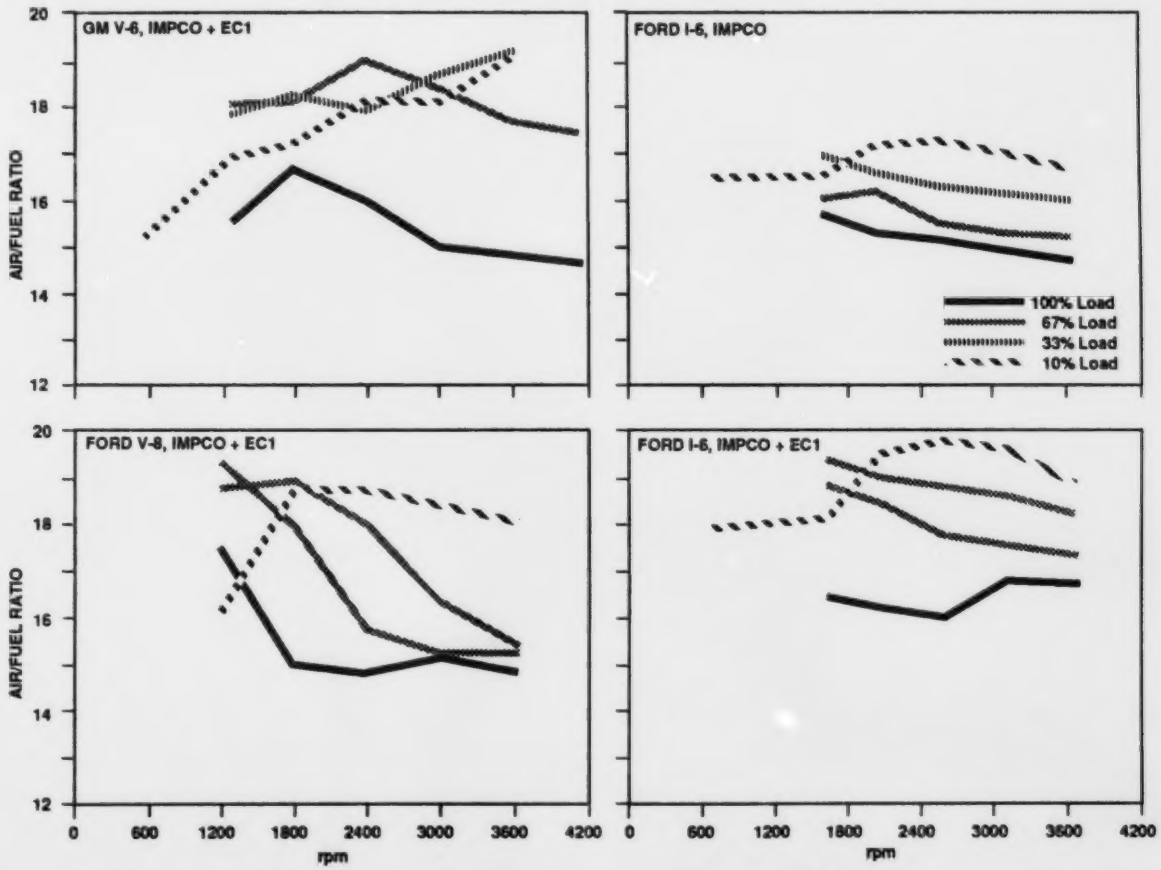

Figure 9/ Air/Fuel Ratio Variation with Speed and Load for IMPCO Propane Conversion

economizer valves in gasoline carburetors.) The Ford I-6 was used to test the IMPCO unit with and without the EC1 device. The figure shows that the addition of this device widens considerably the range of air/fuel ratios between full- and part-load operation and therefore makes a closer approach to the optimum possible. Figure 9 illustrates that the IMPCO system has the range of control of air/fuel ratios necessary to obtain optimum results at both part-load and full-load operation, but doesn't attain the optimum throughout the speed range.

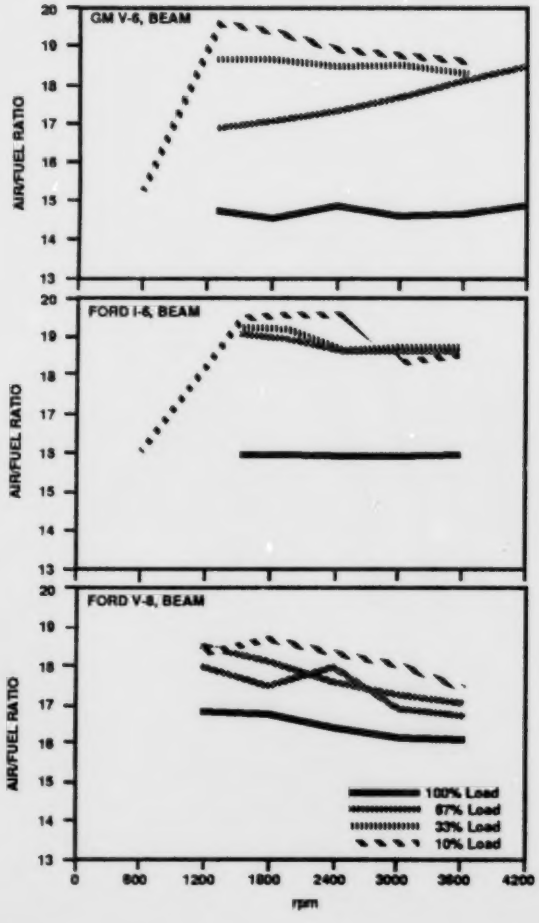

Figure 10/ Air/Fuel Ratio Variation with Speed and Load for Beam Propane Conversion

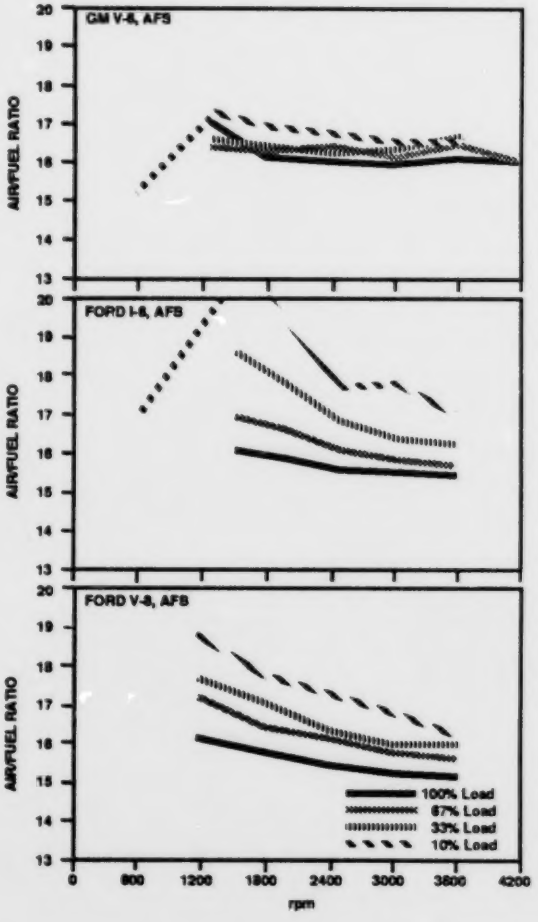

Figure 11/ Air/Fuel Ratio Variation with Speed and Load for AFS Propane Conversion

Figure 10 shows the air/fuel ratios measured with the Beam carburetion equipment on the three engines. For both the GM V-6 and the Ford I-6, the system provides air/fuel ratios reasonably close to optimum throughout the speed range. The range of control exhibited in the Ford V-8 tests is considerably narrower, however. The reason for this is not clear, since the same model vaporizer/ regulator was used for all three tests. The Beam carburetion system has the advantage of being simpler and less susceptible to damage than the IMPCO system.

The control of air/fuel ratio exhibited by the AFS system is shown in Figure 11. The same model vaporizer/regulator was used for all three engines. While this unit has a full-load enrichment device, it did not appear to function in the GM V-6 tests, as the air/ fuel ratio was nearly constant throughout the engine load and speed range. Even in the tests on the other two engines, the AFS system did not have a wide enough range of air/fuel ratios to give both maximum full-load power and minimum part-load fuel consumption. As set up for these tests, the AFS units all operated at an air/fuel ratio throughout the engine load and speed range that resulted in neither good fuel consumption nor maximum power.

In summary, the importance of proper air/fuel ratio has been shown. Since there is a considerable separation of optimum air/fuel ratios for maximum power and for minimum part-load fuel consumption, only a carburetion system offering the widest possible range of air/fuel ratios between partial and full loads should be chosen. Of the equipment tested, Beam and IMPCO units provided the widest range. At its present level of development, the AFS unit does not provide the desired range of control.

4/ RECOMMENDED TUNING PROCEDURES

4.1/ Air/Fuel Ratio

Once a carburetion system has been selected and installed, the air/fuel ratio must be carefully set. To accomplish this, shops performing propane conversions should have an accurate carbon monoxide (CO) analyzer. Best results will be obtained if a chassis dynamometer is available to load the engine to full power. Otherwise, road tests will have to suffice, but in this case the CO analyzer must be portable, so that the exhaust CO can be measured while the vehicle is on the road. (Robert Bosch makes a CO analyzer which operates on 12 VDC.)

The CO meter is used to set the full-power air/fuel ratio. For rich mixtures, the amount of CO in the exhaust increases linearly with a decrease in air/fuel ratio from the chemically correct ratio, as shown by Figure 12. The tests described in the previous section show that maximum power results when the air/fuel ratio is about 14.5. Referring to Figure 12, this air/fuel ratio corresponds to an exhaust gas CO reading of about 2.5%.

For heavy-duty engines, the power adjustment on the carburetion system should be set to produce an exhaust concentration of about 2.5% CO under full load (measured either on the chassis dynamometer or on the road). Several speeds should be checked to ensure that a value close to this is maintained throughout the engine's speed range. This rich mixture is important in heavy-duty applications when a considerable portion of the engine's operating cycle may be at full power, because exhaust gas temperatures are low compared to the chemically correct mixture. IMPCO recommends that a heavy-duty engine operating under continuous full-load conditions should be adjusted no leaner than 1.5 to 2% CO for safety (engine durability).

Since passenger car engines usually operate near full load only for short periods, a less rich mixture of about 1-1.5% CO can be used safely so that the part-load air/fuel ratio will more closely approach the optimum for minimum fuel consumption.

Recall that few of the carburetion systems tested could cover the air/fuel ratio range between about 14.5 for maximum power and about 19 for minimum part-load fuel consumption. Thus, since only one of these can be set, compromise is required. In the case of heavy-duty engines, the compromise is in favour of maximum power and lower exhaust gas temperatures while in the case of the passenger car engine, the compromise is in favour of lower fuel consumption.

While only the full-power mixture can be set, knowledge of the air/fuel ratio the carburetor delivers at part loads is desirable as a guide to establish the amount of vacuum advance that should be used. Air/fuel ratios for mixtures leaner than the chemically correct air/fuel ratio can be determined from Figure 13 with a measurement of the oxygen

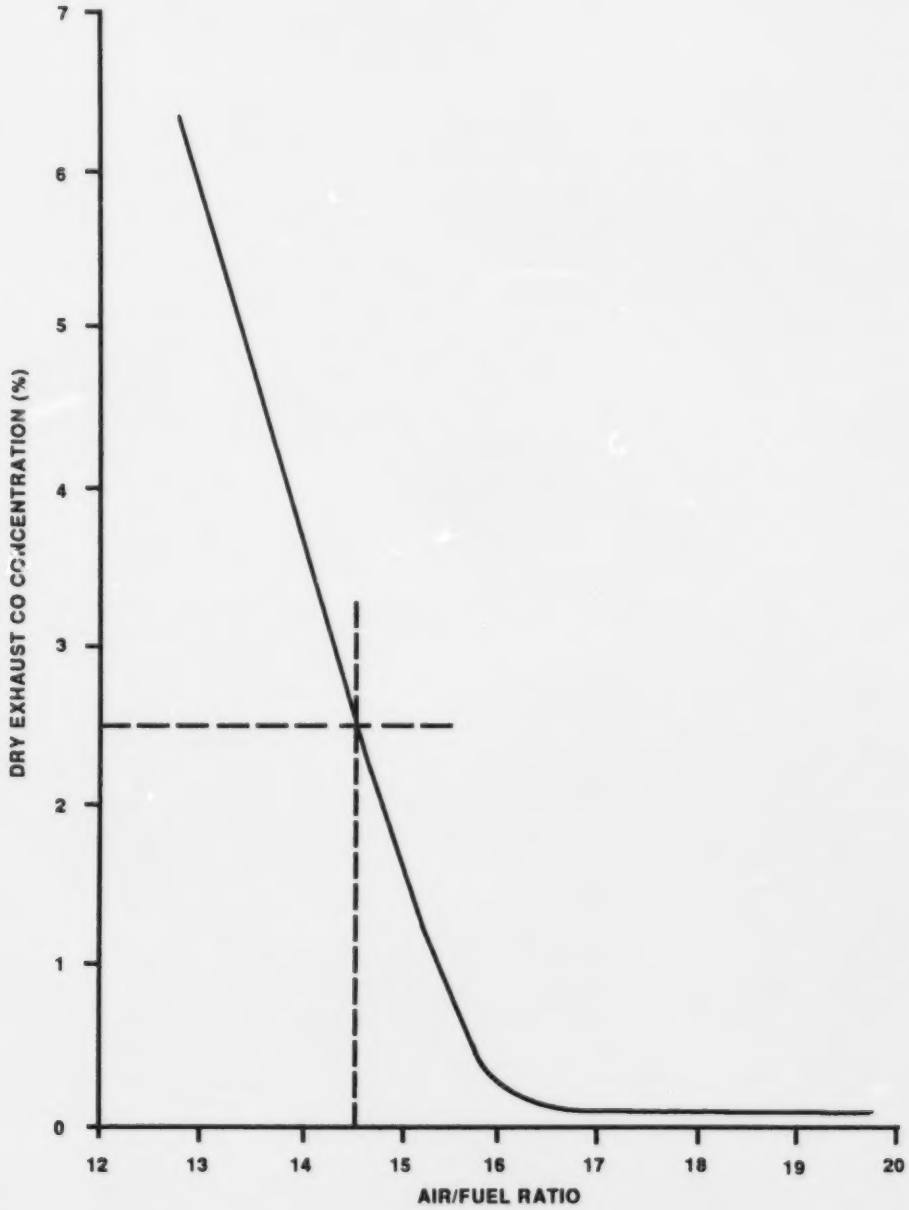

Figure 12/ Variation of Carbon Monoxide in Exhaust with Air/Fuel Ratio

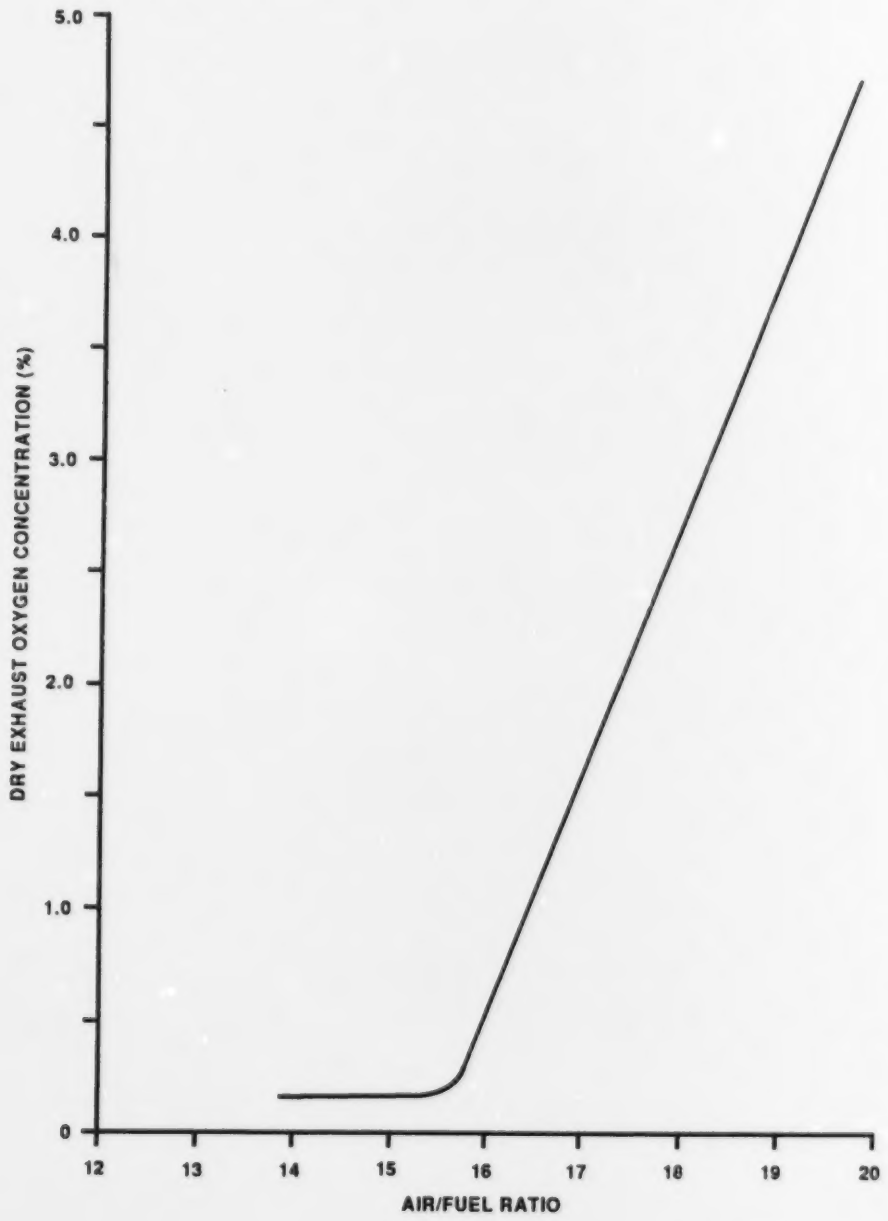

Figure 13/ Variation of Oxygen in Exhaust with Air/Fuel Ratio

concentration in the exhaust. Again, a battery powered portable oxygen meter is available (Teledyne Analytical Instruments Model 320 P-4) which will give excellent results. Exhaust oxygen concentrations should be obtained for no-load and part-load operation at several speeds and used to determine the air/fuel ratios from Figure 13.

4.2/ Ignition Timing

It was shown in the previous section that optimum ignition timing for propane-fuelled engines is considerably different than for the original gasoline-fuelled engine. Unfortunately, the optimum propane timing may differ significantly from engine to engine, making it difficult to provide useful guidelines for adjusting the timing. Establishing the ignition timing curve is the most demanding job facing the shop performing propane conversions.

Ignition timing at full power is the most critical setting since excessive advance can lead to pre-ignition and engine damage while too little advance will result in low power output and excessive exhaust gas temperatures. The optimum timing at full load should be established by dynamometer testing after the proper air/fuel ratio has been set. The general procedure is as follows (see Figure 14):

1/ Disconnect the vacuum advance.

2/ Set the initial timing to the value recommended for gasoline.

3/ Load the dynamometer and stabilize the engine at the desired operating speed and wide open throttle.

4/ Record the power output and ignition timing.

5/ Advance the timing 2° holding the speed constant and record the power output and ignition timing.

6/ Repeat step 5 until 2° advance shows no improvement (or a decrease) in power.

7/ Retard the timing 1° holding the speed constant and check to see that the power remains constant (or increases back to its maximum value). The optimum timing for wide open throttle operation at this speed is 1° less.

This procedure should be repeated for at least two additional speeds so that the centrifugal advance may be properly set. The three speeds should bracket the normal range of engine operating speeds. As an example, test speeds for a truck engine might be 1200 rpm, 2400 rpm and 3600 rpm. Once the optimum timing has been determined for several speeds, a combination of initial (static timing) and centrifugal advance must be chosen to provide these values during engine operation.

The easiest way to do this is to plot a graph such as Figure 15 which shows the optimum timing values for a Ford I-6 at 1600, 2500

and 3500 rpm. The gasoline points are just shown for comparison – they aren't really needed. Note that much more spark advance is required for propane. Draw a vertical line at the engine idle speed, in this case 700 rpm. Using a straight edge, draw a straight line that comes closest to each of the test points as shown in the figure where the sloping dashed line nearly touches each of the three points. Extend this line to intersect the vertical line at the idle speed. The ignition timing value at the intersection (20° BTDC in this example) is the static timing that should be set with the engine idling and the vacuum advance disconnected. Draw a horizontal line from the highest test point to intersect the timing scale on the left. The value shown, in this case 32° BTDC, is the maximum spark advance to be used. The difference between

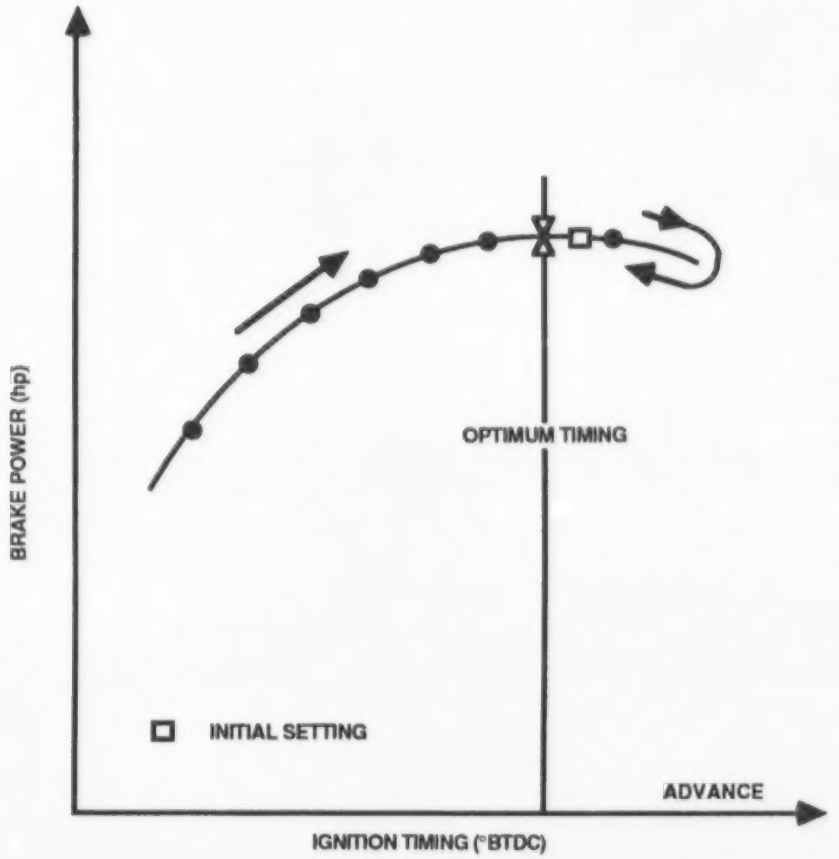

Figure 14/ Timing Optimization for Full Load, Constant Speed, Constant Air/Fuel Ratio

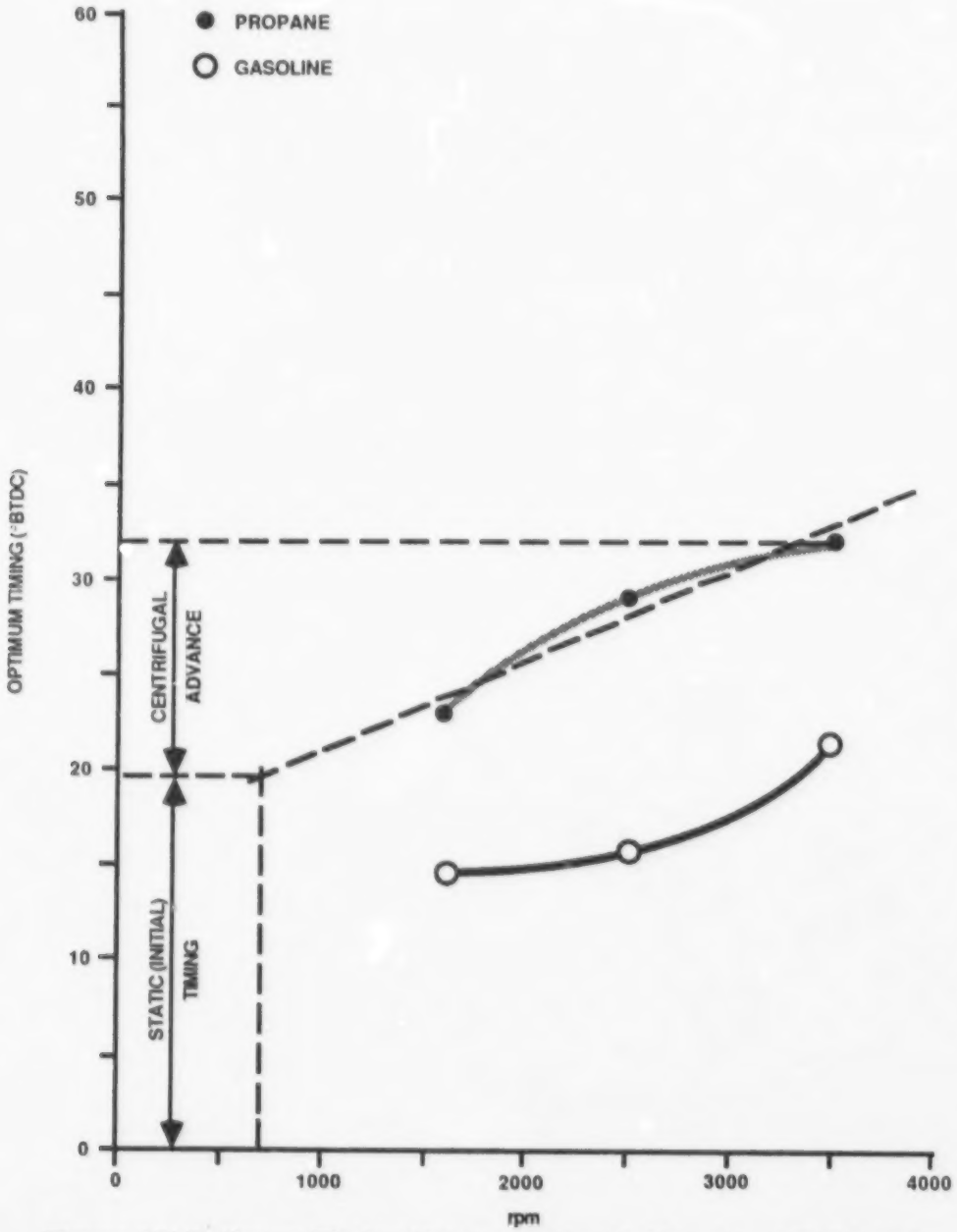

Figure 15/ Optimum Timing Values for Ford I-6 Engine at Full Load

this value and the static timing (32 - 20 = 12˚) is the amount of additional advance to be provided by the centrifugal advance mechanism. Using a distributor machine, the distributor springs and weights should be changed so that there is no centrifugal advance at idle and 12˚ at 3500 rpm. Make sure that the centrifugal advance does not come in faster than this (at a lower speed) or the timing will be too far advanced at lower speeds and could possibly damage the engine.

This procedure is quite time-consuming but it would only have to be done the first time a different type of engine is converted. Additional conversions of the same engine type could simply have the timing set to the optimum values determined for the first one, **as long as the air/fuel ratio is properly set.**

In the event that it is not possible to carry out this procedure, some general guidelines can be given. IMPCO recommends that for heavy-duty engines, an initial spark advance of about 10˚ BTDC should be used with additional centrifugal advance to bring the total to about 27˚- 30˚ by 2000 or 2200 rpm. Diversified Fuel Systems recommends an initial advance of 20˚ with an additional 10˚ of centrifugal advance by 2000 rpm. For the two truck engines tested by UTME (one of which is shown in Figure 15) initial timing of about 20˚ should be used with an additional 10˚ of centrifugal advance by 3600 rpm. The passenger car engine tested by UTME needs less centrifugal advance – initial timing of 18˚- 20˚ with about 5˚ of centrifugal advance by 3600 rpm.

Great caution must be exercised in applying these guidelines to late-model passenger cars. Recently designed passenger car engines have much faster burning combustion chambers than previous designs and will require less spark advance. The proper advance to use for propane in an engine with a fast-burning combustion chamber can only be established by dynamometer testing, but can be expected to be closer to the gasoline timing values than is the case for the three engines evaluated by UTME.

4.3/ Vacuum Advance

The use of vacuum advance will considerably improve the part-load efficiency. The optimum timing for part-load operation is determined on a dynamometer using a procedure similar to that given above, but finding the timing that results in minimum fuel consumption rather than maximum power. This is a time-consuming process, which can only be justified when a large number of identical vehicles are to be converted.

When this procedure cannot be carried out, some general guidelines can be provided. Figure 16 shows the optimum timing for a Ford I-6 engine at one-third and two-thirds of full load as measured on the UTME dynamometer. Optimum timing is shown for

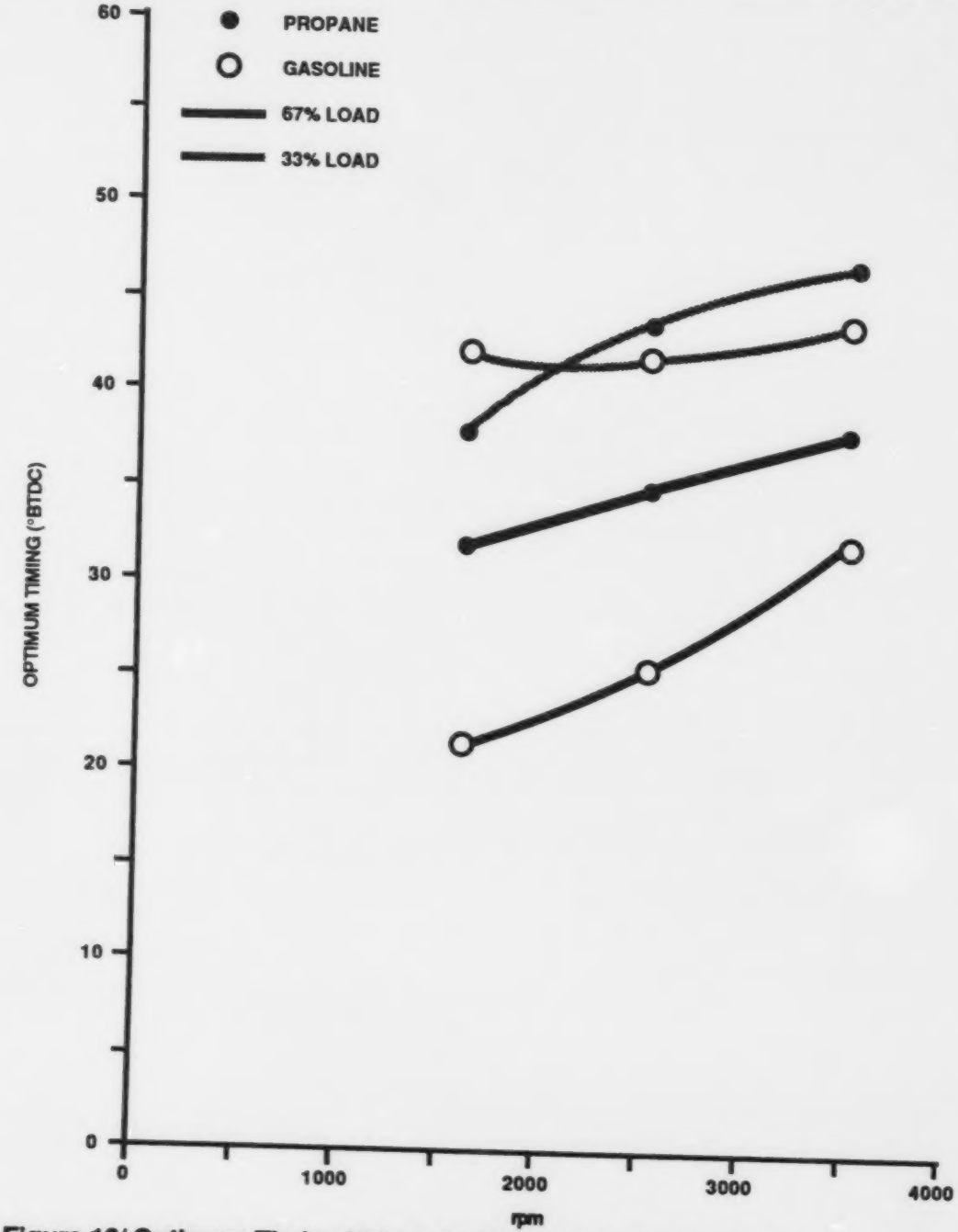

Figure 16/ Optimum Timing Values for Ford I-6 Engine at Part Load

dynamometer. Optimum timing is shown for both propane and gasoline at the three engine speeds tested: 1600, 2500, and 3500 rpm. The total spark advance required at 33% load is essentially the same for propane and gasoline. Since the initial advance with propane is much greater than with gasoline, less vacuum advance should be used. The maximum centrifugal advance and static advance for this engine from Figure 15 was 32°. To get the desired maximum total spark advance of about 47° at one-third load and 3500 rpm, about 15° (47 - 32) of vacuum advance should be used for this engine. These results obtained from the tests with the Ford I-6 are consistent with IMPCO's recommendation for a maximum total spark advance (static advance + centrifugal advance + vacuum advance) of 45°. Thus, having determined the static timing and maximum centrifugal advance using the procedure described previously, the amount of vacuum advance to use can be determined by subtracting the sum of the two from 45°.

All of the above applies to engines with conventional or electronic ignition systems where centrifugal and vacuum advance devices are employed to control the ignition timing. Since no engines with computer controlled ignition systems were tested in the UTME program, it is not possible to give guidelines for their conversion. Most heavy-duty and medium-duty engines, however, have retained electronic ignitions so the information presented above is still widely applicable.

Note: This report is excerpted from a larger, more detailed report, Consolidation and Assessment of Propane Equipment Test Results, by the same authors, which is also available through the Ministry of Transportation at the address shown on the title page.